The Study of the Correlation Between the Most Probable Position of Shadowing of 10TeV Cosmic Rays by the Sun and the Interplanetary Magnetic Field

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Abstract

Studying the shadow of the Sun from 1990 to 1997 in detail, a qualitative explanation to the shift and yearly variation of it is presented. The analysis on a yearly variation of the Sun's shadow and a yearly variation of the mean strength of the solar magnetic field confirmed that there is a correlation between them. Considering the composition of cosmic ray, the quantitative relation between the deviation of the Sun's shadow from its central position and the mean strength of the solar magnetic field is corrected.

1. Introduction

In 1993, the Tibet air-shower array actually observed the Sun's shadow shifted from the apparent solar position. This is the first observation of the effects of the magnetic fields between the Sun and the Earth.[1] A further analysis shows that cosmic-ray by the Sun coming from the away and toward sectors in the interplanetary magnetic field (IMF) move in opposite directions each other [2] and the observed displacement of the Sun shadow is mostly caused by the influence of the solar and interplanetary magnetic fields. [2] Using the data obtained during the period from 1990 through 1993, the Tibet air shower array obtained the results suggest that a time variation of the Sun's shadow is directly sensitive to and is organized by the IMF and its neutral sheet. [3] Studying the relation between the movement of the Sun's shadow and the south-north asymmetry of the solar activity, a conclusion that the shift of the Sun's shadow is shown to be related with the excess days of "toward" or "away" of IMF sectors. [4] The analysis on a yearly variation of the Sun's shadow and a yearly variation of the mean strength of the solar magnetic field confirmed that the deflection of the Sun's shadow is directly proportional to the mean strength of the solar magnetic field and the quantitative relation was obtained. [5] Studying the most probable position of shadowing of 10TeV cosmic rays by the Sun from June 1990 through September 1997 in detail, we present a qualitative explanation to the shift and a yearly variation of it. The analysis on a yearly variation of the Sun's shadow and a yearly variation of the mean strength of the Solar magnetic field confirmed that there is a correlation between them. Considering the composition of cosmic ray, the quantitative relation between the deviation of the Sun shadow from its central position and the mean strength of the solar magnetic field is corrected and the result accords with the experimental better than previous.

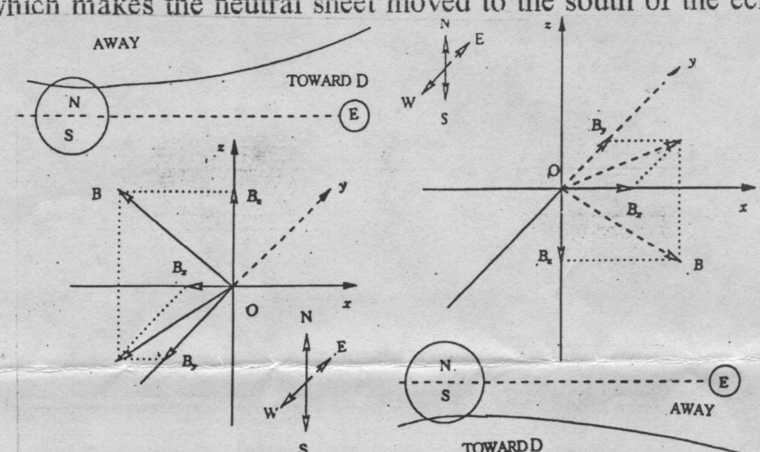
2. The Sun's shadow and the solar activity

The displacement of the Sun's shadow is mostly caused by the influence of the solar and the IMF. Because the azimuthal component of the IMF will make the shadow shifted to the north in the "away" sector and to the south in the "toward" sector and the south-north asymmetry of the solar activity may result in the displacement of the neutral sheet away from the solar ecliptic plane, [6] the displacement of the Sun's shadow is different in different periods of the solar activity. In order to study the variation of the most probable position of the Sun's shadow, we summarized it from 1990 to 1997 in Table 1.

Table 1. the most probable position of the Sun's shadow

year	1990	1991	1992	1993	1996	1997
position	0.8°W,0.1°S	0.7°W,0.8°S	0.3°W,0.5°N	0.2°W,0.0°S	0.14°E,0.00°N	0.06°E,0.06°N

It is known that the IMF is a three dimensional magnetic field. Fig.1 is a schematic plot, showing the IMF component. In this figure, B_z makes the shadow moved to the west-east, B_y makes the shadow moved to the north-south. a) and b) express that the Earth is in the "toward" sector and "away" sector, respectively. Based on this Figure, we can interpret the shift of the Sun's shadow. When the southern hemisphere sunspots exceeds northern ones, which makes the neutral sheet moved to the north of the ecliptic plane and makes B_z turns towards the north, so the Sun's shadow is shifted to the west, meanwhile, the number of days when the Earth in the "toward" sector is larger than "away" sector. So B_y makes the Sun's shadow shift to the south, as is seen in Fig.1a. During the years from 1990 to 1993, because the southern hemisphere sunspots exceeded northern ones, [7] the Sun's shadow was shifted to the south-west. When the northern hemisphere sunspots exceeds southern ones, which makes the neutral sheet moved to the south of the ecliptic plane and makes B_z turns towards the south, so the Sun's shadow is shifted to the east, meanwhile, the number of days when the Earth in the "away" sector is larger than "toward" sector. So B_y makes the Sun's shadow shift to the north, as is seen in Fig.1b. During the years from 1995 to 1997, because the northern hemisphere sunspots exceeded southern ones, [7] the Sun's shadow was shifted to the north-east.



a) Earth in Toward sector; b)Earth in Away sector.

Fig.1 schematic plot of the components of the strength of IMF.

3. The Sun's shadow and the solar magnetic field

Because of the correlation between the Sun's shadow and the solar activity and the shift of the Sun's shadow is due to the feature of the asymmetry of the solar activity and the sunspots is dominated in the solar magnetic field, we image there is a correlation between the Sun's shadow and the solar magnetic field. Comparing the Sun's shadow from 1990 to 1993 and from 1995 to 1997, we can find that the shift of the former is large than the latter. During the years from 1990 to

1993, the Sun near maximum or at the declining phase, the mean strength of the solar magnetic field is larger that the mean strength of the solar magnetic field of years from 1995 to 1997 which the Sun at the quiet phase. All of those set show that there is a correlation between the Sun's shadow and the solar magnetic field.

So, based on the data of Stanford Mean Solar Magnetic Field, we summarized the mean strength of solar magnetic field[7] from 1990 to 1997 in Table 2.

Table 2. summarized the mean strength of solar magnetic field

Year	1990	1991	1992	1993	1994	1995	1996	1997
Stanford(μ T)	47.0	72.1	34.1	26.4	23.6	14.7	9.6	9.3

Integrating Table 2 with Table 1, we can find that the deflection of the Sun's shadow is increased while the mean strength of the solar magnetic field is increased. Using the data of the most probable position of the Sun's shadow and the mean strength of the solar magnetic field from 1990 to 1996, the relative coefficient between them which is 0.92 is obtained, the slope of the simulated line is 0.0135, as is shown in the Fig.2. If the mean strength of the solar magnetic field is B_0 ,then the three dimensional component of the magnetic field satisfied FFF condition can be obtained:

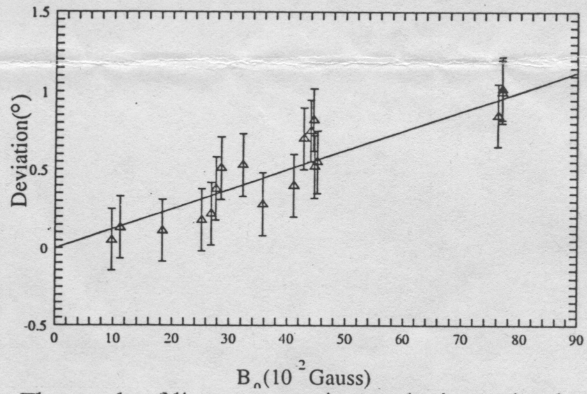


Fig.2 The result of linear regressive analysis on the deviation of the Sun's shadow from its central position and the mean strength of the solar magnetic field, the error bar include systemic error and statistical error.

$$B_x = (-\frac{B_0}{r}) \times \cos\phi(r)$$

$$B_y = B_0 \alpha x y \times \cos\phi(r)/(r+A) - B_0\alpha(z+\alpha) \times \sin\phi(r)/A$$

$$B_z = B_0 \alpha x(z+\alpha) \times \cos\phi(r)/(r+A) + B_0 \alpha y \times \sin\phi(r)$$

Furthermore, according to the relations between the deviation of the Sun's shadow and the momentum of the charged particle and the quantity of electricity and the mean strength of the solar magnetic field which is:

$$\theta = \frac{e}{p}\int_0^{1AU} B dr$$

Thus the equation of deviation of the Sun's shadow and the mean strength of the solar magnetic field can be obtained[5]:

$$\theta = 0.0125 B_0$$

Where the unit of θ is (°), the unit of B_0 is 10^{-6} T. The result accords with the experimental very well.

However, the correction of the forgoing result is necessary, because the composition of cosmic rays was omited. In fact, the composition of cosmic rays is not only protons but also all kinds of nuclear. Using the data of composition of cosmic rays, as is shown in Table 3.[8]

Table 3. the composition of cosmic rays

Electric charge	1	2	3-5	6-9	10-19	20-29
Integrated intensity	610±30	90±2.0	2±0.2	5.6±0.2	1.4±0.2	0.4±0.1

We calculated the composition corrected coefficient is 1.09910, so the corrected relation between the deviation of the Sun's shadow and the mean strength of the solar magnetic field is:

$$\theta = 0.0137B_0$$

the equation of deviation of the Sun's shadow and the mean strength of the solar magnetic field The result accords with the experimental better than previous.

4. conclusion

The observed displacement of the Sun's shadow is mostly caused by the influence of the IMF. The hemispheric asymmetry of solar activity, as represented by the number of sunspots, may result in the displacement of the neutral sheet away from the more active solar hemisphere, thus move the average position of the neutral sheet in the interplanetary space away from the solar ecliptic plane, which makes the Sun's shadow varied. When southern hemisphere sunspots exceeds northern ones, the average position of the neutral sheet moved to the north of the ecliptic plane. So, the Sun's shadow is deflected away from the Sun to the south-west; when northern hemisphere sunspots exceeds southern ones, the average position of the neutral sheet moved to the south of the ecliptic plane. So, the Sun's shadow is deflected away from the Sun to the north-east. Because sunspots dominated in the solar mean magnetic field, there is a correlation between the shift of Sun's shadow and the solar mean magnetic field. The deflection of the Sun's shadow is directly proportional to the mean strength of the solar magnetic field and the quantitative relation was obtained.

However, considering the south-north asymmetry of solar activity and the Sun's shadow will be varied in north-south or west-east during a long time, but the experience of the study of the Sun's shadow is less than a solar activity and the solar cycle is now in a quiet phase, but it will go toward the next active phase starting from about the year 2000, so we expect that the further observation will confirm the aforementioned topics and give further results.

References

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